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Trends in socioeconomic inequalities in underweight and obesity in 5-year-old children, 2011–2018: a population-based, repeated cross-sectional study

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ABSTRACT

Objective To explore trends in prevalence and socioeconomic inequalities in underweight and obesity in 5-year-old schoolchildren in Scotland between 2011/2012 and 2017/2018.

Design A population-based, repeated cross-sectional study.

Setting Local authority primary schools in Scotland.

Participants 373 189 5-year-old schoolchildren in Scotland between 2011/2012 and 2017/2018.

Methodology Trends in prevalence and inequalities in underweight and obesity were examined across seven school years (2011/2012–2017/2018) for 373 189 5-year-old schoolchildren in Scotland. Body mass index SD scores were calculated, and epidemiological cut-offs relative to the UK 1990 references categorised underweight and obesity. Slope/relative indices of inequality (SII/RII) were calculated for underweight and obesity by school year using the area-based Scottish Index of Multiple Deprivation.

Results The prevalence of obesity rose slightly overall during the study period (9.8% in 2011/2012; 10.1% in 2017/2018). However, this masked a widening of inequalities, with children from the most deprived areas experiencing a greater risk of obesity in 2017/2018 than in 2011/2012 (risk ratio=1.14, 95% CI 1.04 to 1.25) compared with an unchanged risk in children from the least deprived areas (risk ratio=0.95, 95% CI 0.82 to 1.11). SII and RII indicate widening inequalities for obesity, with RII rising from 1.95 (95% CI 1.71 to 2.22) in 2011/2012 to 2.22 (95% CI 1.93 to 2.56) in 2017/2018. The prevalence of underweight was consistently low (compared with the UK 1990 references) and remained unchanged over the study period (1.2% in 2011/2012; 1.1% in 2017/2018), with no consistent evidence of social patterning over time.

Conclusions Inequalities in obesity in schoolchildren in Scotland are large and have widened from 2011, despite only a slight rise in overall prevalence. In contrast there has been little change in underweight prevalence or inequalities during the study period. Extra resources for policy implementation and measures which do not widen inequalities and focus on reaching the most deprived children are required to tackle the high prevalence and growing inequalities in childhood obesity in Scotland.

Strengths and limitations of this study

- This is a large population-based, individual child-level analysis capturing 90.5% of the 5-year-old children living in Scotland between 2011/2012 and 2017/2018.
- Novel analyses of contemporary large administrative and health data sets collected routinely were performed using measures of absolute and relative inequalities.
- This is the first time a study of this size has reported on inequalities in underweight and obesity in a contemporary population sample during a period of austerity policies.
- Individual-level socioeconomic measures were not available as part of routine administrative data.
- Obesity is an excess of body fatness rather than an excess of body weight which body mass index measures and therefore we could be underestimating effects.

INTRODUCTION

In 2015, an estimated 5% (107.7 million) of children worldwide had obesity,[1] and although the prevalence of childhood obesity in many high-income countries appears to be levelling off[2] there is evidence in the UK to suggest that it is not consistent across all socioeconomic groups.[3 4] Obesity is not the only form of malnutrition which is a cause for concern in childhood; there is increasing recognition of the need to consider the 'double-burden' of malnutrition, even in high-income countries.[5] Double burden refers to the coexistence (potentially at individual, family, community and national level) of both underweight and obesity, even in high-income countries.[5] Double burden matters because of the multiple adverse developmental and health consequences of both forms of malnutrition in early life.[5]

In the late 1990s in Scotland both underweight and obesity in early childhood were

much more prevalent than expected compared with the UK reference data from 1990, and both were socially patterned (much higher risk in more socioeconomically deprived families).[6] Very little is known about more recent trends and inequalities in the double burden of underweight and obesity in children in the UK. Inequalities in childhood underweight and obesity may have worsened due to dramatic changes in the social and economic environment in the past decade. Life expectancy growth in the UK has stalled and health inequalities widened[7] in the last decade of austerity (policies which produced massive public spending cuts with consequent loss of health and social services, reductions in welfare benefits and increased food insecurity).[7] One English school study on over five million children conducted between 2007 and 2012 showed widening inequalities in the prevalence of obesity over time, low prevalence of underweight and no evidence of inequalities in underweight changing during the study period.[3]

More recent trends in the double burden, and whether or not inequalities in the double burden are widening or narrowing, can be identified in Scotland because population-level body mass index (BMI) data are routinely collected, on an opt-out basis, on primary 1 (typically aged 5 years old at some point in the school year) schoolchildren as part of the Child Health Systems Programme School (CHSP-S).[8] This is an important time to monitor population BMI as it corresponds to the physiological nadir of the growth curve in childhood and represents a transitional stage for children in terms of changing food and physical patterns. Reports on the prevalence of underweight, healthy weight, overweight and obesity are published annually by the Scottish Government; however, changes in patterns of inequalities have not been fully examined using measures of inequality. Other surveys conducted in Scotland lack population-level numbers, consistent methods and reporting on deprivation.[9 10]

With efforts to mitigate the impact of rising food insecurity and child poverty in Scotland through free school meals, breakfast clubs and food banks, there is a clear need to monitor recent trends and inequalities in underweight and obesity, as the mitigation of underweight could inadvertently lead to increasing the risk of obesity. This understanding should help inform policy and track progress towards the Scottish Government's target to halve the prevalence of childhood obesity by 2030 and to reduce health inequality more generally.[11] In summary, we need to understand recent trends in the double burden of early childhood malnutrition in order to test whether recent economic and policy changes have reduced or increased social inequality in Scotland. Improved understanding of trends in Scotland may also be helpful for other high-income countries—in general public health nutrition research and policy in high-income countries has neglected childhood underweight.[5]

Aim

The aim was to explore the trends in prevalence and socioeconomic inequalities in underweight and obesity in 5-year-old schoolchildren in Scotland from 2011/2012 to 2017/2018.

METHODS

Data sources

Data for this population-based, child-level analysis were collected annually between 2011/2012 and 2017/2018 as part of the CHSP-S, a population-level data set routinely collected by Public Health Scotland (PHS) (formerly Information Services Division (ISD)) of the National Health Service (NHS) Scotland. The CHSP-S offers a review to all children in primary 1 (typically aged 4–5 years old at the start of the school year) of local authority schools and some private schools. Measurements are conducted on a parental/carer opt-out basis at any point within the school year by healthcare professionals, generally school nursing teams, who are trained to Royal College of Paediatrics and Child Health guidelines.[12] Children's heights are measured in centimetres to one decimal place and weights in kilograms to two decimal places.[13]

CHSP-S collected data on the child's date of birth and examination date—for which an age at examination could be calculated—sex and area-based socioeconomic deprivation. Area-based deprivation, measured by the Scottish Index of Multiple Deprivation (SIMD) at a national level,[14] is based on the child's home postcode. SIMD is an area-level measure of relative deprivation based on 38 indicators of deprivation categorised into seven domains (income, employment, health, housing, geographical access, crime, and education, skills and training). The list of areas was ordered by deprivation and split into tenths, where areas in SIMD 1 represent the 10% most deprived areas and areas in SIMD 10 represent the 10% least deprived. The SIMD was used in accordance with PHS (published as ISD) guidelines[15] and CHSP-S publications,[4] using SIMD 2012[16] for examinations between 2011/2012 and 2013/2014 and SIMD 2016[17] for examinations between 2014/2015 and 2017/2018.

In 2011/2012, CHSP-S captured 95.0% (n=52 972) of the National Records of Scotland's (NRS) 5-year-old population estimate of 55 769 children. In 2017/2018, CHSP-S captured 88.4% (n=53 016) of the NRS estimate of 60 001. PHS suggests the reasons for decline in coverage include shortage of staff to conduct reviews and technical issues with recording review findings in the system.[18] The decline was distributed equally across the socioeconomic scale and for each sex and thus should have no effect on the results.

Patient and public involvement

The project for which this study is involved in was scrutinised and approved by the NHS Scotland information governance board, the Public Benefit and Privacy Panel. This study involved secondary analyses of routine administrative

and health data sets, and all data were fully anonymised and made available to us for analyses within the National Safe Haven.[19] Therefore, the patients or the parent/guardian of the patient could not be involved in the study.

Definitions

SD scores (SDS) for BMI (BMI= $\frac{weight\ (kg)}{height\ (m)^2}$) were calculated based on Cole *et al*'s UK 1990 references.[20] Using epidemiological age-specific and sex-specific cut-offs, children in <2nd centile (SDS circa <−2) were classed as underweight and children in ≥95th centile (SDS circa ≥1.645) had obesity. Children who were overweight (≥85th centile and <95th centile; SDS circa ≥1.036 and <1.645) were kept separately from children of healthy weight (≥2nd centile and <85th centile; SDS circa ≥−2 and <1.036), although as our focus was on the double burden of underweight and obesity the results for overweight were not included in the main analysis.

Inclusion criteria

The study included individual records from pupils from all NHS Health Boards in Scotland who were between 4.0 and 7.0 years old inclusive (referred to as 5 years old herein) in Scottish Local Authority (and some private) schools for the school years 2011/2012–2017/2018 that had a record for the CHSP-S review. Initially there were 374 067 children. After excluding children due to age limits, extreme values for BMI SDS and height/weight SDS,[18] and missing data for deprivation, the final sample consisted of 373 189 children (online supplemental figure S1).

Statistical analysis

The analyses were conducted within the NHS National Safe Haven[19] and reported following best practice guidance.[21 22] Data cleaning and statistical analyses were completed using RStudio V.1.2.1335[23] and various packages within the program.[24–29]

Trends in prevalence and inequalities in underweight and obesity were calculated across seven school years: from 2011/2012 to 2017/2018. Line graphs were used to show the change in prevalence of underweight and obesity over the years according to sex and area-based deprivation (SIMD). Linear regression was used to examine if the prevalence of each disease had changed over the years.

Differences between sex and area-based deprivation (SIMD) overall and over time were estimated using a modified Poisson regression model, which uses a binary outcome of underweight versus healthy weight and obesity versus healthy, with interaction terms for school years (as a continuous variable) with both sex and SIMD, separately in the same model. Risk ratios (RR) were calculated by taking the exponential of the model estimate and 95% CIs calculated using robust SEs.

To investigate whether the risk of underweight and obesity had increased in 2017/2018 vs 2011/2012, the modified Poisson regression models described above were used, although the sex variable was removed. Linear combination analysis was used to compare the prevalence of underweight and obesity in 2017/2018 vs 2011/2012 partitioned within each tenth of area-based deprivation (SIMD). RRs were calculated by taking the exponential of the sum of the estimate for 2017/2018 and the respective SIMD tenth and year interaction term, and robust SEs were used to calculate 95% CIs.

Recognising that inequalities cannot be captured in a single number, absolute and relative inequalities were calculated by the slope index of inequality (SII) and the relative index of inequality (RII), with 95% CIs, respectively, for the prevalence of underweight and obesity. The SII and RII were modelled using additive and multiplicative Poisson regression, respectively, using the rate of underweight and obesity versus healthy weight as the dependent variable and the midpoint of the cumulative population for each tenth of the socioeconomic scale, ranked from the least deprived to the most deprived, as the independent variable for each school year over the study period,[30] using robust SEs. The SII should be interpreted as the absolute inequality in underweight and obesity, respectively, between the top and bottom of the socioeconomic scale in terms of rate difference.[31] The RII should be interpreted as the ratio of the underweight and obesity rates of those from the most deprived areas compared with those from the least deprived areas.[31] To test the hypothesis of increasing or decreasing trend in SII and RII, a linear regression modelled using the SII and RII estimates was regressed against the school year (treated as a continuous variable).

Population attributable risk (PAR) is a measure of the potential impact of control measures in a population, which can be relevant to public health decisions.[32] The PAR for social deprivation was calculated by subtracting the prevalence of underweight and obesity in those in the least deprived tenth (SIMD 10) from the overall prevalence. Dividing by the overall prevalence of the condition gave population attributable risk percentage (PAR%), which was used to estimate the percentage of disease that could be avoided if the risk factor (deprivation in this instance) was removed.[33] This was calculated for 2011/2012 and 2017/2018 for underweight and obesity separately.

RESULTS

Data completeness

The seven cohorts represented 93.6% (n=52 173/55 769), 94.6% (n=53 944/57 021), 91.7% (n=54 556/59 490), 91.1% (n=54 498/59 796), 91.0% (n=53 222/58 497), 84.6% (n=52 164/61 695) and 87.7% (n=52 632/60 001) of the NRS population estimate for the seven school years, respectively (online supplemental table S1).

The cohorts had an overall sex split of 50.9% (n=190 100/373 189) male and 49.1% (n=183 089/373 189) female. The SIMD distribution was skewed to the right, with the highest proportion of observations in SIMD 1 (most deprived tenth; 12.2%) and the lowest in SIMD 10 (least deprived; 8.7%) (online supplemental table S2), which is consistent with the NRS birth records.[34]

Figure 1 Prevalence of underweight (A) and obesity (B) in 5-year-old schoolchildren in Scotland overall and by sex from school years 2011/2012 to 2017/2018 (online supplemental table S3).

Trends in the prevalence of underweight and obesity by sex

Figure 1 shows the prevalence of underweight and obesity for boys, girls and overall over time (2011–2018). Overall, the prevalence of underweight ranged from 1.2% in 2011/2012 (n=635/52 173) to 1.1% in 2017/2018 (n=560/52 632; β=0.0, 95% CI −0.1 to 0.0, p=0.27) (figure 1A, online supplemental table S3). The prevalence of underweight within the female population was 0.9% (n=228/25 507) in 2011/2012 and 0.7% (n=185/25 735) in 2017/2018 (β=0.0, 95% CI −0.1 to 0.0, p=0.07), while the prevalence of underweight in the male population was 1.5% (n=407/26 666) and 1.4% (375/26 897) for 2011/2012 and 2017/2018, respectively (β=0.0, 95% CI −0.1 to 0.0, p=0.27). Boys had a higher risk of being underweight than girls (RR=1.68, 95% CI 1.46 to 1.93, p<0.001), with this risk being consistent over the years (p for sex/year interaction=0.26).

The overall prevalence of obesity was 9.8% (n=5111/52 173) in 2011/2012 and 10.1% (n=5336/52 632) in 2017/2018 (β=0.1, 95% CI 0.0 to 0.2, p=0.15) (figure 1B, online supplemental table S3). The prevalence of obesity within girls was 9.5% both in 2011/2012 (n=2424/25 507) and 2017/2018 (n=2456/25 735; β=0.1, 95% CI −0.1 to 0.3, p=0.27). The male prevalence of obesity was 10.1% (n=2687/26 666) in 2011/2012 and 10.7% (n=2880/26 897) in 2017/2018 (β=0.1, 95% CI 0.0 to 0.3, p=0.11). Boys had a higher risk of having obesity compared with girls (RR=1.06, 95% CI 1.02 to 1.11, p=0.004), although the risk was consistent over the years (p for sex/year interaction=0.46).

Trends in socioeconomic inequalities in underweight and obesity

Within children from the 10% most deprived areas (SIMD 1), the prevalence of underweight was 1.2% (n=75/6355) in 2011/2012 and 1.1% (n=70/6246) in 2017/2018 (β=0.0, 95% CI 0.0 to 0.1, p=0.86) (figure 2A, online supplemental table S4). The prevalence of underweight in the 10% least deprived areas (SIMD 10) was 1.1% (n=51/4439) in 2011/2012, reducing to 0.8% (n=40/4837) in 2017/2018 (β=−0.1, 95% CI −0.2 to 0.0, p=0.08).

The prevalence of obesity in children from the 10% most deprived areas increased from 11.9% (n=755/6355) to 13.5% (845/6246) between 2011/2012 and 2017/2018 (β=0.3, 95% CI 0.0 to 0.6, p=0.030) (figure 2B). The prevalence in the 10% least deprived areas remained steady over the years, where 6.6% (n=295/4439) of children had obesity in 2011/2012 and 6.4% (n=308/4837) in 2017/2018 (β=0.0, 95% CI −0.3 to 0.2, p=0.60) (figure 2B).

Changes in risk of underweight and obesity in 2011/2012–2017/2018 according to area-based deprivation

There was no change in risk of underweight in 2017/2018 for children from the 10% most deprived areas in Scotland (RR=0.97, 95% CI 0.70 to 1.34, p=0.86) when compared with children from the same areas in 2011/2012

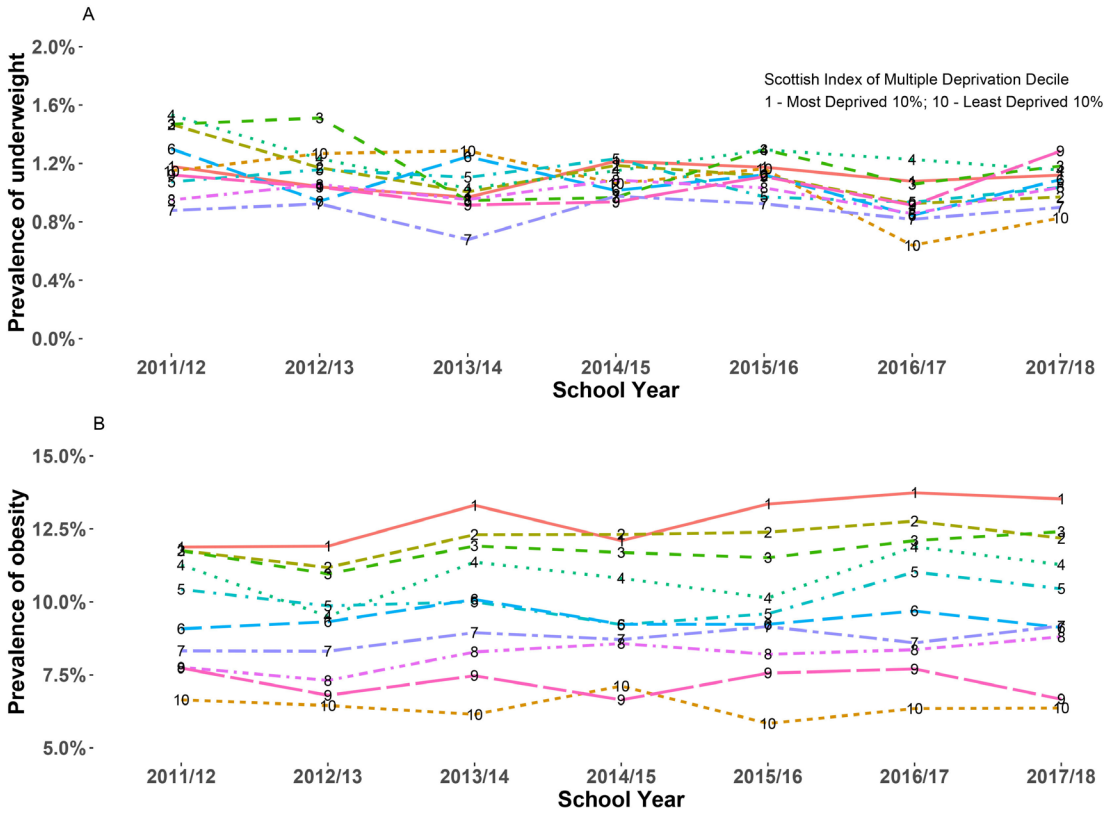

Figure 2 Prevalence of underweight (A) and obesity (B) in 5-year-old schoolchildren in Scotland by area-based deprivation (Scottish Index of Multiple Deprivation) from 2011/2012 to 2017/2018 (online supplemental table S4).

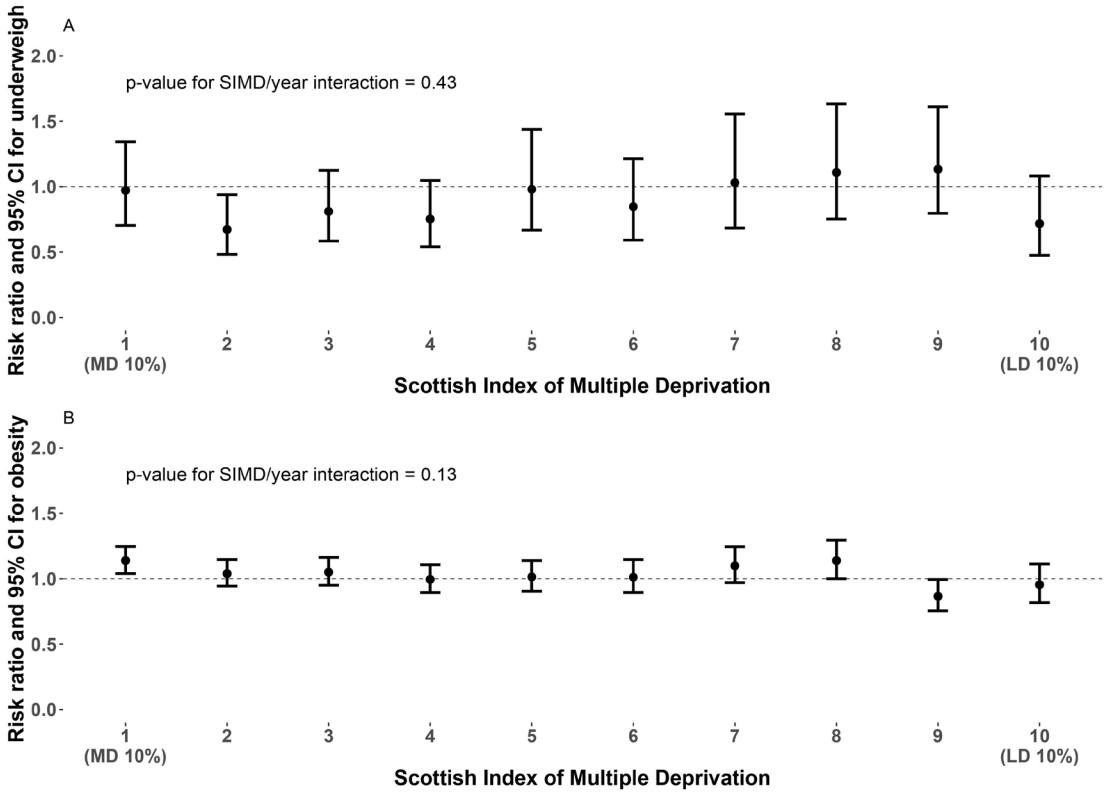

Figure 3 Risk ratio and 95% CI for the prevalence of underweight (A) and obesity (B) in 2017/2018 vs 2011/2012 for each decile of the Scottish Index of Multiple Deprivation. LD, least deprived; MD, most deprived; SIMD, Scottish Index of Multiple Deprivation.

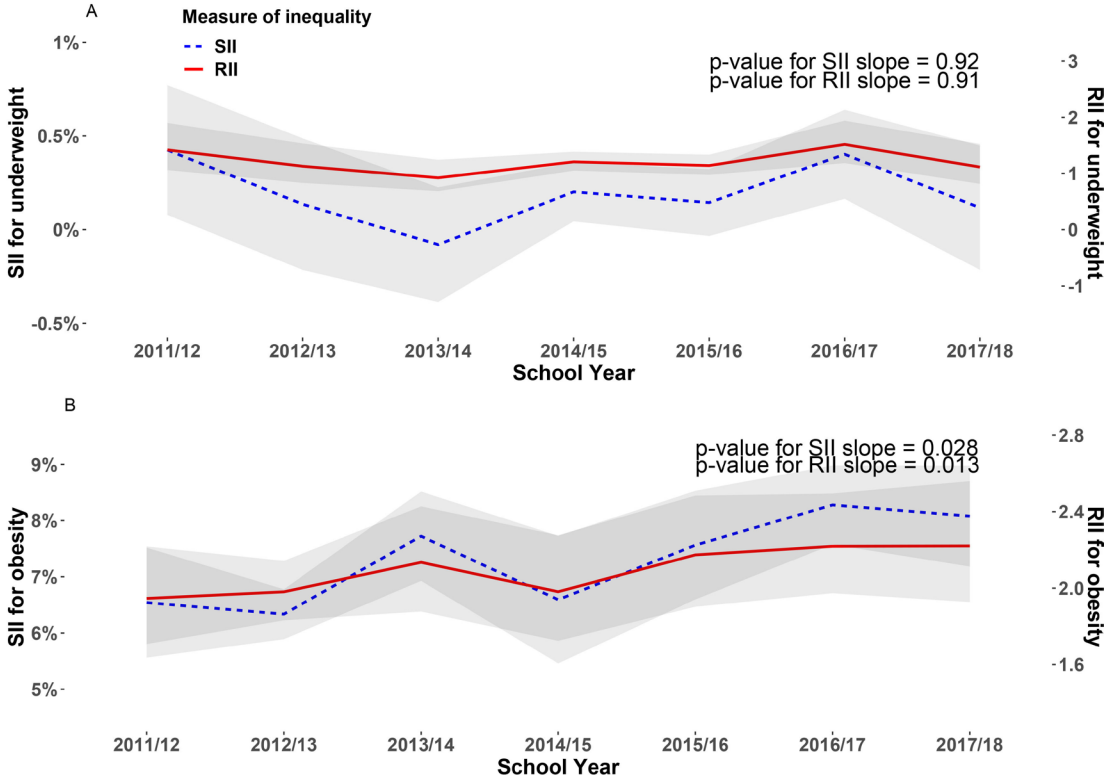

Figure 4 Slope and relative index of inequalities and 95% CIs for prevalence of underweight (A) and obesity (B) from 2011/2012 to 2017/2018 for 5-year-old schoolchildren in Scotland. RII, relative index of inequality; SII, slope index of inequality (online supplemental table S5).

(figure 3A). Similarly, the risk of underweight did not change for children in the 10% least deprived areas between 2011/2012 and 2017/2018 (RR=0.72, 95% CI 0.47 to 1.08, p=0.11). The only change in risk of underweight between 2011/2012 and 2017/2018 was evident in children from SIMD 2, where children in 2017/2018 had a lower risk of underweight than their counterparts in 2011/2012 (RR=0.67, 95% CI 0.48 to 0.94, p=0.019).

Although the prevalence of obesity remained constant overall in Scotland, children from the 10% most deprived areas had an increased risk of obesity in 2017/2018 than in 2011/2012 (RR=1.14, 95% CI 1.014 to 1.25, p=0.005) (figure 3B), while the risk remained unchanged in children from the 10% least deprived areas (RR=0.95, 95% CI 0.82 to 1.11).

SII and RII for underweight and obesity

In 2011/2012 there was evidence to suggest that there were absolute and relative inequalities in the prevalence of underweight between the most and the least deprived areas (SII=0.4, 95% CI 0.1 to 0.8; RII=1.42, 95% CI 1.06 to 1.90), followed by fluctuations in both SII and RII over the study period, with no systematic trend observed (figure 4A, online supplemental table S5).

For obesity, the SII was estimated at 6.5 (95% CI 5.6 to 7.5) in 2011/2012, rising to 8.1 (95% CI 7.2 to 9.0) in 2017/2018, with evidence to suggest the absolute inequalities followed an upward trend (slope=0.30, 95% CI 0.05 to 0.55, p=0.028) over the study period (figure 4B, online supplemental table S5). The RII, too, followed an upward trend (slope=0.05, 95% CI 0.01 to 0.08, p=0.013) between 2011/2012 and 2017/2018, rising from 1.95 (95% CI 1.71 to 2.22) to 2.22 (95% CI 1.93 to 2.56) (figure 4B, online supplemental table S5).

PAR% for underweight and obesity

The PAR% for obesity in 2017/2018 suggests that 37.2% (n=1984/5365, 95% CI 29.0% to 45.3%) of cases of obesity in 5-year-old schoolchildren could have been avoided if inequalities were eradicated, rising from 32.2% (n=1645/5111, 95% CI 23.7% to 40.6%) in 2011/2012. The equivalent calculations for underweight in 2017/2018 suggested 22.2% (n=124/560, 95% CI −59.0% to 100.0%) of cases of underweight in 5-year-old schoolchildren could be avoided, rising from 5.6% (n=35/635, 95% CI −65.8% to 77.1%) in 2011/2012; however, these estimates for underweight should be interpreted with caution due to the small numbers and large CIs.

DISCUSSION

Main findings and study implications

This population-based, child-level analysis of over 350 000 5-year-old children in Scotland between 2011/2012 and 2017/2018 is the first study, to our knowledge, to examine trends in socioeconomic inequalities in both underweight and obesity during a decade of austerity economic policies in the UK. Overall, the prevalence of

obesity has risen very slightly; however, this has masked widening inequalities due to higher and increasing levels of obesity in children from more deprived areas, and lower plateauing levels of obesity in children from less deprived areas.

Despite increasing concern over the public health impact of the increasing levels of child poverty,[35] food insecurity and the use of food banks in the UK over the past decade of austerity,[7] there is very little evidence on prevalence, trends and inequalities in childhood underweight. In contrast to obesity findings in the present study, the prevalence of underweight across the seven school years was consistently low relative to the UK 1990 references, with no evidence of an increase or decrease and no clear social gradient observed over the years. These results for the underweight population are best taken with caution due to the low prevalence, and thus small sample size, of underweight in the study. Any misclassification of children with BMI SDS close to the cut-off for underweight could drastically change the results presented in this study.

Comparisons with other studies

As noted above, awareness of the double burden has increased only recently, and there has been a perception that early childhood underweight is a public health problem for low-income to middle-income countries rather than high-income countries.[5] As a result, there are relatively few similar studies from high-income countries which can be compared against the findings of the present study. This dearth of evidence also means that the causes of social inequalities and widening inequalities are poorly understood. Further research will be required to understand why social inequalities in early childhood underweight decreased in Scotland from the late 1990s[6] to 2011/2012 (present study), and then remained relatively stable from 2011/2012, and why social inequalities in early childhood obesity increased over the decade of austerity in the UK as suggested by the present study. This could be part of a wider picture observed across England in recent years, with a report from the Health Foundation reporting on falling life expectancy in people from the most disadvantaged (and marginalised) groups. Although it is difficult to attribute causality, this report strongly suggests that a decade of austerity has adversely impacted the social determinants of health in the short, medium and long term, with the impact of child poverty most likely showing their effects in the long term.[7]

In a previous Scottish study of social inequalities of underweight and obesity in early childhood which used routinely collected data from 1998/1999, there was marked social patterning of both underweight and obesity in those years.[6] We are not aware of any Scottish trend data in social patterning of childhood underweight and obesity since that time.

Despite some methodological and consent differences, White *et al*[8] in an earlier analysis of routine data from children aged 5 and 11 years old in England showed similar widening inequalities in obesity, but these remained stable for underweight, and suggested more sophisticated implementation of policy to protect the health of children from the poorest areas.

A slowing of previous increases in childhood obesity prevalence in the past decade has been observed in other high-income countries, probably due to increased awareness of the problem and/or public policy efforts.[36 37] However, our study shows that childhood obesity over the past decade in Scotland has not only increased in prevalence but has experienced marked widening inequalities. Reducing health inequalities is a high priority of public health policy in the UK, so the trends observed in obesity inequality in the present study are unwelcome. In addition, the PAR% estimates for obesity from this study give cause for concern because they suggest that the inequalities observed have affected large numbers of individuals, and in future years they will contribute substantially to inequalities in non-communicable diseases given the well-established comorbidities of childhood obesity.[36 37]

Marmot *et al*[38] highlighted the importance of experiences in early years to later health outcomes with inequalities at this age having potential lasting impact throughout the child's life.[36] This is reinforced again by Marmot *et al*,[7] noting that at this age interventions to reduce inequalities which focus on proportionate universalism are most effective and are shown to be the most cost-effective. As noted above, the double burden of early childhood underweight and obesity is a relatively new concern for high-income countries and the issue of social inequalities in the double burden is even newer, so there is a dearth of evidence of interventions intended to reduce inequalities in the double burden. However, in general terms the evidence suggests that public health interventions which operate 'upstream' are both more likely to be effective and less likely to increase social inequalities than interventions which operate 'downstream', focusing on individuals.[39]

Strengths and limitations

The study's main strength is the high capture rate of the population in primary 1 in Scottish schools from large routinely collected administrative data sets, and this is the first time a study of this size has reported on inequalities in underweight and obesity in a contemporary population sample during a period of austerity policies.

Our study used population-wide administrative data sets established for other purposes and therefore the variables available were limited. The data set had regular quality and completeness checks. The linkage process was robust and did not exclude many records from the expected total in the published reports. Due to our study having a high linkage rate, it is a representative cohort of the population.

Limitations in this study mainly come from the BMI measurement. Obesity is an excess of body fatness rather than an excess of body weight.[40] Since body fatness is difficult to measure directly in large population-based

surveys, a high BMI-for-age is used widely as a proxy for high body fatness.[41] Using BMI-for-age as a proxy underestimates 'true' obesity substantially compared with excessive fatness.[42] It is therefore likely that the true obesity prevalence in Scotland is greater than the estimates presented which were based on BMI-for-age and that we have provided conservative estimates of obesity prevalence among 5-year-olds in Scotland.

The proportion of children reviewed from the population estimate reduced in each year of the study, although this change was proportionate across socioeconomic groups (online supplemental table S2). Children from more deprived areas are more likely to be absent from school than their less deprived peers,[43] so may be missed by the reviews; however, those children attending private schools (1%–2% of population)[4] may also be underrepresented. It is unlikely either group will sufficiently change the direction of the results. The proportion of children in each area-based deprivation tenth is consistent with NRS population estimates.[34]

Individual-level socioeconomic measures were not available as part of the routine administrative data and therefore area-based deprivation level was used. This has limitations when targeting individuals based on inferences made about the group (ie, ecological fallacy) and does not allow for heterogeneity in individual-level risk factors and disease levels within areas of residence.[44]

CONCLUSIONS

This large population-based, child-level analysis suggests that the prevalence of childhood obesity has slightly risen, while absolute and relative socioeconomic inequalities in Scotland are large and worsening over time. In contrast, the prevalence of underweight was low, not obviously socially patterned, with no obvious change over the study period despite increasing levels of child poverty. Extra resources for policy implementation and measures which do not widen inequalities and focus on reaching the most deprived children are required to tackle the high prevalence and growing inequalities in obesity among children in Scotland.

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Contributors RS designed the study, developed the statistical design, wrote the statistical analysis plan, performed the statistical analysis, collated all reviewer comments and updated accordingly, and wrote the manuscript. JJR designed the study, provided critical review of the findings and wrote the manuscript. AH designed the study, provided critical review of the findings and wrote the manuscript. LAK developed the statistical design, provided critical review of the statistical analysis and wrote the manuscript. DC wrote the grant for the overall project, designed the study, provided critical review of the findings and wrote the manuscript. DY developed the statistical design, provided critical review of the statistical analysis and wrote the manuscript. AS wrote the grant for the overall project, designed the study, developed the statistical design, provided critical review of the findings and wrote the manuscript. All authors reviewed and approved the final manuscript.

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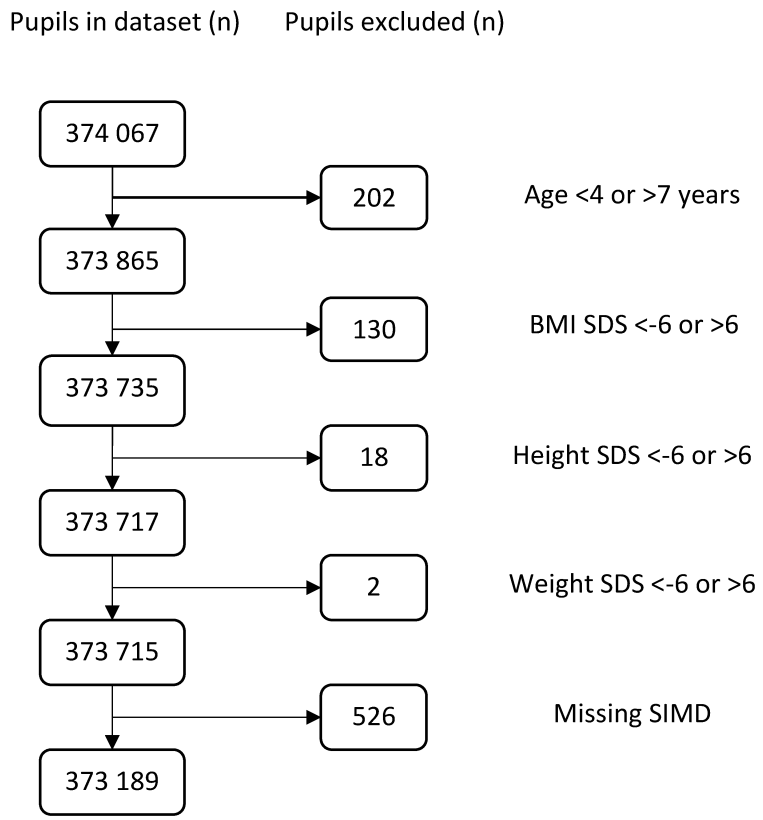

Figure S1 - Flow chart of data cleaning with number of 5-year-old schoolchildren lost at each step. BMI – Body Mass Index; SDS – Standard Deviation Score; SIMD – Scottish Index Multiple Deprivation

S1 Table. Total number of 5-year-old schoolchildren in Scotland in CHSP-S publication and study cohort and proportion found in National Records Scotland population estimates by school year

School Year	2011/12		2012/13		2013/14		2014/15		2015/16		2016/17		2017/18	
	n	%	n	%	n	%	n	%	n	%	n	%	n	%
NRS	55 769		57 021		59 490		59 796		58 497		61 695		60 001	
CHSP-S	52 972	95.0	55 004	96.5	55 494	93.3	55 492	92.8	54 165	92.6	53 626	86.9	53 016	88.4
Study	52 173	93.6	53 944	94.6	54 556	91.7	54 498	91.1	53 222	91.0	52 164	84.6	52 632	87.7

NRS – National Records Scotland population estimates of 5-year-old children in Scotland

CHSP-S – Total number of 5-year-old schoolchildren in Scotland recorded by Child Health Surveillance Programme – School

Study – Total number of 5-year-old schoolchildren in Scotland in the study's cohort with valid measurements

S2 Table. Total of number of 5-year-old school children in Scotland in the study cohort by area-based deprivation (SIMD) and sex by school year

School Year	**2011/12**		**2012/13**		**2013/14**		**2014/15**		**2015/16**		**2016/17**		**2017/18**		**Total**	
	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%
SIMD																
1 (MD)	6355	12.2	6734	12.5	6822	12.5	6499	11.9	6471	12.2	6588	12.6	6246	11.9	45 715	12.2
2	5792	11.1	6064	11.2	6169	11.3	6067	11.1	6094	11.5	6055	11.6	5869	11.2	42 110	11.3
3	5242	10.0	5557	10.3	5497	10.1	5687	10.4	5558	10.4	5389	10.3	5497	10.4	38 427	10.3
4	5219	10.0	5354	9.9	5342	9.8	5309	9.7	5180	9.7	5216	10.0	5197	9.9	36 817	9.9
5	4938	9.5	5100	9.5	5428	9.9	5188	9.4	5045	9.5	4817	9.2	4822	9.2	35 268	9.5
6	5000	9.6	5096	9.4	5057	9.3	4927	9.0	4809	9.0	4737	9.1	4868	9.2	34 494	9.2
7	5238	10.0	5415	10.0	5454	10.0	5017	9.2	4982	9.4	4767	9.1	4892	9.3	35 765	9.6
8	5050	9.7	5116	9.5	5141	9.4	5342	9.8	5129	9.6	5022	9.6	5111	9.7	35 911	9.6
9	4900	9.4	5013	9.3	5139	9.4	5447	10.0	5224	9.8	5037	9.7	5293	10.1	36 053	9.7
10 (LD)	4439	8.5	4495	8.3	4507	8.3	5085	9.3	4730	8.9	4536	8.7	4837	9.2	32 629	8.7
Sex																
Male	26 666	51.1	27 409	50.8	27 797	51.0	27 665	50.8	27 035	50.8	26 631	51.1	26 897	51.1	190 100	50.9
Female	25 507	48.9	26 535	49.2	26 759	49.0	26 833	49.2	26 187	49.2	25 533	48.9	25 735	48.9	183 089	49.1
Total	**52 173**		**53 944**		**54 556**		**54 498**		**53 222**		**52 164**		**52 632**		**373 189**	

SIMD – Scottish Index of Multiple Deprivation; MD – Most Deprived; LD – Least Deprived

S3 Table. Prevalence of BMI status by Scotland overall and sex by school year in 5-year-old schoolchildren in Scotland

School Year	2011/12		2012/13		2013/14		2014/15		2015/16		2016/17		2017/18		β	95% CI for β	p
	n	%	n	%	n	%	n	%	n	%	n	%	n	%			
Scotland																	
Underweight	635	1.2	611	1.1	549	1.0	592	1.1	598	1.1	490	0.9	560	1.1	0.0	(-0.1, 0.0)	0.27
Healthy	40 112	76.9	41 838	77.6	41 641	76.3	42 042	77.1	40 870	76.8	39 751	76.2	40 257	76.5	-0.1	(-0.3, 0.1)	0.20
Overweight	6315	12.1	6464	12.0	6809	12.5	6546	12.0	6494	12.2	6477	12.4	6479	12.3	0.0	(-0.1, 0.1)	0.33
Obesity	5111	9.8	5031	9.3	5557	10.2	5318	9.8	5260	9.9	5446	10.4	5336	10.1	0.1	(0.0, 0.2)	0.15
Male																	
Underweight	407	1.5	388	1.4	358	1.3	388	1.4	378	1.4	326	1.2	375	1.4	0.0	(-0.1, 0.0)	0.27
Healthy	20 267	76.0	21 003	76.6	21 021	75.6	21 169	76.5	20 625	76.3	20 139	75.6	20 310	75.5	-0.1	(-0.3, 0.1)	0.29
Overweight	3305	12.4	3386	12.4	3481	12.5	3327	12.0	3302	12.2	3314	12.4	3332	12.4	0.0	(-0.1, 0.1)	0.78
Obesity	2687	10.1	2632	9.6	2937	10.6	2781	10.1	2730	10.1	2852	10.7	2880	10.7	0.1	(0.0, 0.3)	0.11
Female																	
Underweight	228	0.9	223	0.8	191	0.7	204	0.8	220	0.8	164	0.6	185	0.7	0.0	(-0.1, 0.0)	0.07
Healthy	19 845	77.8	20 835	78.5	20 620	77.1	20 873	77.8	20 245	77.3	19 612	76.8	19 947	77.5	-0.1	(-0.4, 0.1)	0.18
Overweight	3010	11.8	3078	11.6	3328	12.4	3219	12.0	3192	12.2	3163	12.4	3147	12.2	0.1	(0.0, 0.2)	0.10
Obesity	2424	9.5	2399	9.0	2620	9.8	2537	9.5	2530	9.7	2594	10.2	2456	9.5	0.1	(-0.1, 0.3)	0.27

CI – Confidence Interval

S4 Table. Prevalence of BMI status by area-based deprivation (SIMD) and school year in 5-year-old schoolchildren in Scotland

School Year	2011/12		2012/13		2013/14		2014/15		2015/16		2016/17		2017/18		β	95% CI for	p
	n	%	n	%	n	%	n	%	n	%	n	%	n	%			
SIMD 1 (MD)																	
Underweight	75	1.2	70	1.0	66	1.0	79	1.2	76	1.2	71	1.1	70	1.1	0.0	(0.0, 0.1)	0.86
Healthy Weight	4685	73.7	5005	74.3	4970	72.9	4763	73.3	4659	72.0	4778	72.5	4503	72.1	-0.3	(-0.6, -0.1)	0.017
Overweight	840	13.2	857	12.7	878	12.9	871	13.4	872	13.5	834	12.7	828	13.3	0.0	(-0.1, 0.2)	0.65
Obesity	755	11.9	802	11.9	908	13.3	786	12.1	864	13.4	905	13.7	845	13.5	0.3	(0.0, 0.6)	0.030
SIMD 2																	
Underweight	85	1.5	71	1.2	62	1.0	72	1.2	68	1.1	56	0.9	57	1.0	-0.1	(-0.1, 0.0)	0.038
Healthy Weight	4305	74.3	4530	74.7	4521	73.3	4496	74.1	4504	73.9	4397	72.6	4322	73.6	-0.2	(-0.5, 0.1)	0.13
Overweight	721	12.4	785	12.9	827	13.4	752	12.4	767	12.6	829	13.7	775	13.2	0.1	(-0.1, 0.4)	0.27
Obesity	681	11.8	678	11.2	759	12.3	747	12.3	755	12.4	773	12.8	715	12.2	0.2	(0.0, 0.4)	0.09
SIMD 3																	
Underweight	77	1.5	84	1.5	52	0.9	55	1.0	72	1.3	57	1.1	65	1.2	0.0	(-0.2, 0.1)	0.34
Healthy Weight	3887	74.2	4159	74.8	4055	73.8	4265	75.0	4129	74.3	3978	73.8	4065	73.9	-0.1	(-0.3, 0.2)	0.40
Overweight	662	12.6	705	12.7	735	13.4	702	12.3	717	12.9	702	13.0	685	12.5	0.0	(-0.2, 0.2)	0.93
Obesity	616	11.8	609	11.0	655	11.9	665	11.7	640	11.5	652	12.1	682	12.4	0.1	(-0.1, 0.3)	0.14
SIMD 4																	
Underweight	80	1.5	66	1.2	55	1.0	61	1.1	67	1.3	64	1.2	60	1.2	0.0	(-0.1, 0.1)	0.52
Healthy Weight	3877	74.3	4098	76.5	4018	75.2	4020	75.7	3927	75.8	3880	74.4	3888	74.8	-0.1	(-0.5, 0.4)	0.35
Overweight	674	12.9	681	12.7	662	12.4	654	12.3	661	12.8	652	12.5	663	12.8	0.0	(-0.1, 0.1)	0.83
Obesity	588	11.3	509	9.5	607	11.4	574	10.8	525	10.1	620	11.9	586	11.3	0.1	(-0.3, 0.5)	0.48
SIMD 5																	
Underweight	53	1.1	59	1.2	60	1.1	63	1.2	49	1.0	45	0.9	50	1.0	0.0	(-0.1, 0.0)	0.08
Healthy Weight	3757	76.1	3955	77.5	4156	76.6	3955	77.3	3910	77.5	3654	75.9	3618	75.0	-0.2	(-0.6, 0.2)	0.30
Overweight	613	12.4	583	11.4	669	12.3	628	12.3	602	11.9	587	12.2	650	13.5	0.2	(-0.1, 0.4)	0.21
Obesity	515	10.4	503	9.9	543	10.0	472	9.2	484	9.6	531	11.0	504	10.5	0.1	(-0.2, 0.4)	0.56
SIMD 6																	
Underweight	65	1.3	48	0.9	63	1.2	50	1.0	54	1.1	40	0.8	53	1.1	0.0	(-0.1, 0.1)	0.37
Healthy Weight	3848	77.0	3997	78.4	3823	75.6	3788	76.9	3732	77.6	3647	77.0	3713	76.3	-0.1	(-0.6, 0.4)	0.59
Overweight	633	12.7	576	11.3	661	13.1	634	12.9	579	12.0	591	12.5	658	13.5	0.1	(-0.2, 0.5)	0.39
Obesity	454	9.1	475	9.3	510	10.1	455	9.2	444	9.2	459	9.7	444	9.1	0.1	(0.0, 0.3)	0.06
SIMD 7																	
Underweight	46	0.9	50	0.9	37	0.7	49	1.0	46	0.9	39	0.8	44	0.9	0.0	(-0.1, 0.1)	0.99
Healthy Weight	4118	78.6	4282	79.1	4260	78.1	3906	77.9	3865	77.6	3714	77.9	3820	78.1	-0.2	(-0.4, 0.0)	0.10
Overweight	638	12.2	633	11.7	669	12.3	625	12.5	615	12.3	604	12.7	579	11.8	0.0	(-0.2, 0.2)	0.71
Obesity	436	8.3	450	8.3	488	8.9	437	8.7	456	9.2	410	8.6	449	9.2	0.1	(0.0, 0.3)	0.06
SIMD 8																	
Underweight	48	1.0	54	1.1	49	1.0	58	1.1	53	1.0	43	0.9	53	1.0	0.0	(0.0, 0.0)	0.31

Healthy Weight	4065	80.5	4107	80.3	4028	78.4	4211	78.8	4078	79.5	3954	78.7	4046	79.2	-0.2	(-0.6, 0.1)	0.18
Overweight	545	10.8	581	11.4	638	12.4	615	11.5	577	11.2	605	12.0	562	11.0	0.0	(-0.3, 0.3)	0.86
Obesity	392	7.8	374	7.3	426	8.3	458	8.6	421	8.2	420	8.4	450	8.8	0.2	(0.0, 0.4)	0.040
SIMD 9																	
Underweight	55	1.1	52	1.0	47	0.9	51	0.9	58	1.1	46	0.9	68	1.3	0.0	(-0.1, 0.1)	0.50
Healthy Weight	3922	80.0	4052	80.8	4123	80.2	4466	82.0	4184	80.1	4033	80.1	4274	80.7	0.0	(-0.4, 0.4)	0.89
Overweight	544	11.1	568	11.3	585	11.4	568	10.4	587	11.2	570	11.3	598	11.3	0.0	(-0.2, 0.2)	0.85
Obesity	379	7.7	341	6.8	384	7.5	362	6.6	395	7.6	388	7.7	353	6.7	0.0	(-0.3, 0.2)	0.72
SIMD 10 (LD)																	
Underweight	51	1.1	57	1.3	58	1.3	54	1.1	55	1.2	29	0.6	40	0.8	-0.1	(-0.2, 0.0)	0.08
Healthy Weight	3648	82.2	3653	81.3	3687	81.8	4172	82.0	3882	82.1	3716	81.9	4008	82.9	0.1	(-0.1, 0.3)	0.18
Overweight	445	10.0	495	11.0	485	10.8	497	9.8	517	10.9	503	11.1	481	9.9	0.0	(-0.3, 0.3)	0.99
Obesity	295	6.6	290	6.5	277	6.1	362	7.1	276	5.8	288	6.3	308	6.4	0.0	(-0.3, 0.2)	0.60

SIMD – Scottish Index of Multiple Deprivation; MD – Most Deprived; LD – Least Deprived; CI – Confidence Interval

S5 Table. Results for Slope & Relative Index of Inequality for 5-year-old schoolchildren in Scotland with underweight and obesity

School Year	**2011/12**	**2012/13**	**2013/14**	**2014/15**	**2015/16**	**2016/17**	**2017/18**	**p for trend**
N	52 173	53 944	54 556	54 498	53 222	52 164	52 632	
Underweight								
n	635	611	549	592	598	490	560	
SII	0.4	0.1	-0.1	0.2	0.1	0.4	0.1	0.92
(95% CI)	(0.1, 0.8)	(-0.2, 0.5)	(-0.4, 0.2)	(0.0, 0.4)	(0.0, 0.3)	(0.2, 0.6)	(-0.2, 0.4)	
RII	1.42	1.13	0.92	1.21	1.14	1.52	1.11	0.91
(95% CI)	(1.06, 1.90)	(0.83, 1.53)	(0.68, 1.24)	(1.05, 1.39)	(0.98, 1.33)	(1.19, 1.94)	(0.81, 1.52)	
Obesity								
n	5111	5031	5557	5318	5260	5446	5336	
SII	6.5	6.3	7.7	6.6	7.6	8.3	8.1	0.028
(95% CI)	(5.6, 7.5)	(5.9, 6.8)	(6.9, 8.5)	(5.5, 7.7)	(6.6, 8.5)	(7.6, 9.0)	(7.2, 9.0)	
RII	1.95	1.98	2.13	1.98	2.17	2.22	2.22	0.013
(95% CI)	(1.71, 2.22)	(1.83, 2.14)	(1.88, 2.43)	(1.72, 2.28)	(1.90, 2.48)	(1.97, 2.49)	(1.93, 2.56)	

SII – Slope Index of Inequality; RII – Relative Index of Inequality; CI – Confidence Interval